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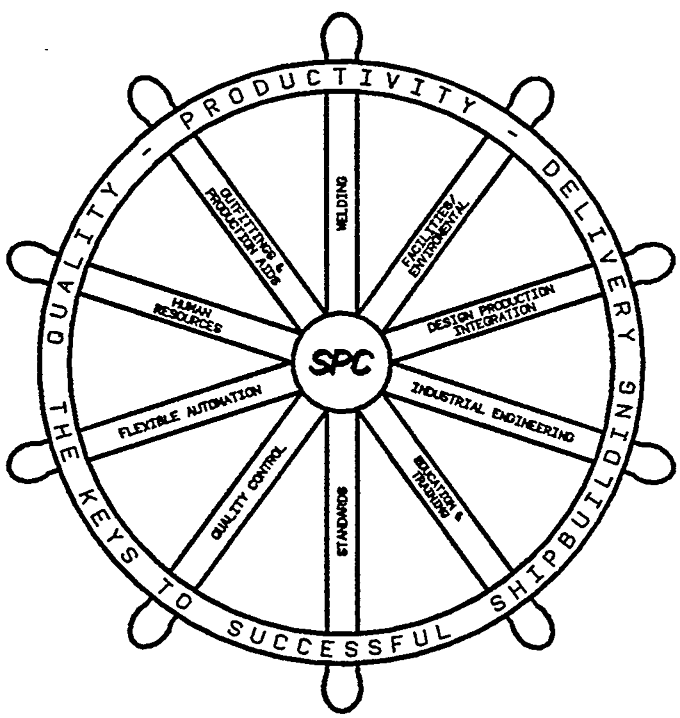

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Shell Development Computer Aided Lofting - Is There a Problem or Not?

Thomas Lamb (F)-Textron Marine Systems, a Division of Textron,Inc.

ABSTRACT

Some shipyards are not satisfied with the computer aided shell development systems that they use. This is because of fit up problems and the need for excess material to allow corrections to be made at erection. Most shipbuilders desire a "cut to neat size" approach.

Most CAL developers recommend that excess material be used. They claim that this is to take care of limitations in the plater's skill and the forming machinery, not in the CAL system.

The paper reports on a study that was undertaken to determine the correct perspective for the shell plate development problem and if the shipbuilder's goal of cutting all shell plates neat is reasonable.

NOMENCLATURE

BSRA	British Ship Research Association
CAL	Computer Aided Lofting
NASSCO	National Steel & Shipbuilding Company
N/C	Numerically Controlled
NSRP	National Shipbuilding Research Program
MarAd	Maritime Administration

INTRODUCTION

Computer aided shell plate development methods have been in use for approximately 30 years. At first the computer approaches simply duplicated the traditional manual ship lofting approaches. In fact, early versions of computer aided lofting systems emphasized this as an advantage, in the hope that the traditional lofstmen would be more willing to accept the "new" tool if they knew it emulated how they manually performed the same task.

The demand for improved accuracy, plus the evolving capabilities of computers and software, resulted in improvements to all the areas of computer aided lofting, including shell plate development.

Unfortunately, even with these improvements, most shipbuilders are still dissatisfied with the accuracy of the current computer shell plate development. The shipbuilders' goal is to cut every shell plate neat (with no excess material around the developed shape to allow for the inaccuracies at fit up). More specifically, they want to be able to erect a block to another block with the erection joints matching perfectly, thus minimizing rework at the erection stage. Most shipbuilders report that they cannot do this for shell plates with any shape other than simple curvature in the transverse direction, which can be simply rolled.

To help put the shell plate development problems in their correct perspective and to attempt to determine if the goal of cutting all shell plates neat is reasonable, a study was tided by the SP-4 Panel with the following objectives:

- To obtain the participation of existing shipbuilding and aerospace computer aided lofting system developers/users to discuss:
  - Shell development problems
  - The methods they use to develop shell plate and handle the problems
  - Any stipulated limitations in application
- To select five (5) shell plates representative of the "difficult" type as test cases to be developed by the participating computer aided lofting system developers.

BACKGROUND

The development of the shell plates of a ship has been a necessary shipbuilding skill since the introduction of iron ships. Early shipwrights/platers did not develop shell plates. The Ioftsmen laid the lines of frames on a screive board. Templates were then made for each frame from the Rune lines on the screive board. The actual flmes were then shaped to

the templates. Once the frames were erected and secured by the deck beams and ribbands, the shell plates were "lifted off" theframes by wood tip templates (patterns). The template was used to transfer the flat shape to the plate which was marked and then cut. As the seams and butts were either lapped or strapped and riveted , accuracy was not as essential as it became for welded ships and is today for modem shipbuilding methods. Also, the shape of the shell plates was kept as simple as possible by following the "natural" straking for the hull shape.

As can be well imagined this approach was very labor intensive. The practice of lofting and shell plate development from the full scale frame body plan on the loft floor was a natural development in the progress of shipbuilding technology at that time.

The first attempt to improve on the full scale lofting approach was the fairing of ship's lines by using the method of differences. This was a manual calculation approach that improved on the time taken to fair lines, but it was still labor intensive and required more highly educated technicians to apply it. Once the fairing was complete it was still necessary to lay down the frame lines on the loft floor and the development of shell plates and frame templates were lifted in the traditional manner.

The first major break from the traditional loft and lofting was the 1:10 scale lofting developed in Germany by Sicomat in the late 1950's. Some developments based on this approach were the optical projection of the 1:10 drawing to full scale on the plate for marking, and the electronic optical following controller that could direct a burning machine.

The manual development of shell plating required skilled and experienced loftsmen. In an attempt to improve on the manual method and to reduce dependence on skilled loftsmen, the G.A.G. Plate Development Jig was developed in Germany in the early 1960's. It was a logical development in parallel with the 1:10 lofting and burning machines.

About the time that the optical tracing 1:10 system was being put into practice, a number of organizations and countries were developing computer aided lofting (CAL) systems, and computer or numerical controlled burning and marking machines.

While the British and the Scandinavians were the most successful in putting CAL into practice, in the early 1960's, the U.S. did experiment with numerically controlled (N/C) burning machines at the Todd shipyard in Seattle under a MarAd funded study. Unfortunately for the U.S. nothing came of it.

The British system was developed by the British Ship Research Association (BSRA) which was jointly funded by the major British shipbuilders with significant support from the British government. Their charter was to develop systems that would give the British shipyards a competitive advantage through technology, so there was no interest to expand the use of BSW systems in other countries. In fact the opposite was the case.

On the other hand both the Norwegian AUTOKON and the Swedish STEERBEAR systems were marketed aggressively around the world. AUTOKON was marketed in the U.S. by COM/CODE CorporatiorL which had obtained the Iicence for it in the U.S. and Canada. COM/CODE licenced AUTOKON to Newport News in 1972, and in 1973 gave a special licence to MMA4 which in turn, could licence up to ten individual U.S. shipbuilders. However, the anticipated number of shipyards did not purchase the AUTOKON licences, perhaps because the decline in U.S. commercial shipbuilding had already started.

General Dynamics had been a user of the AUTOKON system before COM/CODE obtained their licence and continued to use it.

Bethlehem Steel shipyard instaIled an N/C burning and marking machine in 1966 and tried to develop its own system but was unsuccessful. In 1974 it joined the MarAd sponsored AUT-OKON users' group.

Avondale shipyard developed its own system under the direction of Fil Cali, which eventually developed into the SPADES system currently used by Avondale, Ingalls, Ma.rinette Marine, NASSCO, and Lockheed (before it closed).

Since then the different CAL systems have become more user friendly, efficient integrated and capable of providing shipbuilding oriented user data. With the exception of FORAN, which developed as a design system and then added lofting, these systems were first developed as a computer aided manufacturing (CAM) tool. Over the years they have been extended back into design and planning to offer a "total shipbuilding system."

Lofting methods developed for steel shipbuilding were used by early aircraft manufacturers. Both Boeing and McDonnel Douglas later developed their own CAL systems. Both of these systems have since been used for ship lofting and shell plate development but the results have been no better than that offered by the shipbuilding CAL systems.

In the last decade, simpler and lower cost systems for ship lofting have been developed with the aid of the personal computer. While these do not offer all the capabilities of the established total shipbuilding systems, they do offer a lower cost alternative for a

shipbuilder to obtain a CAL and N/C generating capability.

Today some shipbuilders still believe that there are definite limitations to the use of computer aided shell development systems. Blocks in tie modern modular shipbuilding approach are designed with transverse butts, and horizontal joining seams. This results in the joining plate having significant twist and backset in certain parts of the forward and aft lower shoulders. Some blocks constructed recently in the U.S. have been out of alignment by 2 to 3 inches at the comers of the block.

Some U.S. shipbuilders claim that the Japanese shipbuilders cut all plates neat and rdl blocks without stock and they fit! However, at the 1992 NSRP Symposium (1) it was reported that a major Japanese shipbuilding group were currently far from acheiving this goal. Sixteen to 30% of their formed shell plates required back stripping or cutting and they always left stock on bow and stem blocks. This is not too different from U.S. shipyard practice. Another Japanese shipbuilder is reported to leave only 1/4 inch when stock is required and if it fits well when erected to the adjacent block it is simply left on. Otherwise it is used for fit-up adjustment.

Most CAL system developers recommend that stock material be left on one seam and one butt for each block that has significant curvature. Many say this is to take care of inaccuracies due to the platers' skill level and limitations of the forming machinery, rather than compensate for inaccuracies in the plate development. Today, most shipbuilders desire a "cut to neat size" approach. This is obviously to eliminate labor intensive fitting, cutting in and edge preparation on the building berth or plattens. However, it appears unattainable. Why is this? The SP-4 Limitations of Computerized Lofting study was performed to attempt to answer if it is.

SHELL PLATE DEVELOPMENT PROBLEMS

In performing this study it was determined that shell plate development problems are viewed differently by shipbuilders and the CAL developers. This is surprising when it is remembered that computer aided lofting shell development methods have been in use for over twenty years. It would seem reasonable to expect developers and users (shipbuilders) to have worked out the problems or at least agreed what they are. However, as will be seen from the following discussion this does not appear to be the case.

Before discussing the problems, it is necessary to define some of the terms that will be used.

CURVATURE is smooth deviation from a straight line. As applied to a surface it is smooth deviation from a flat plane.

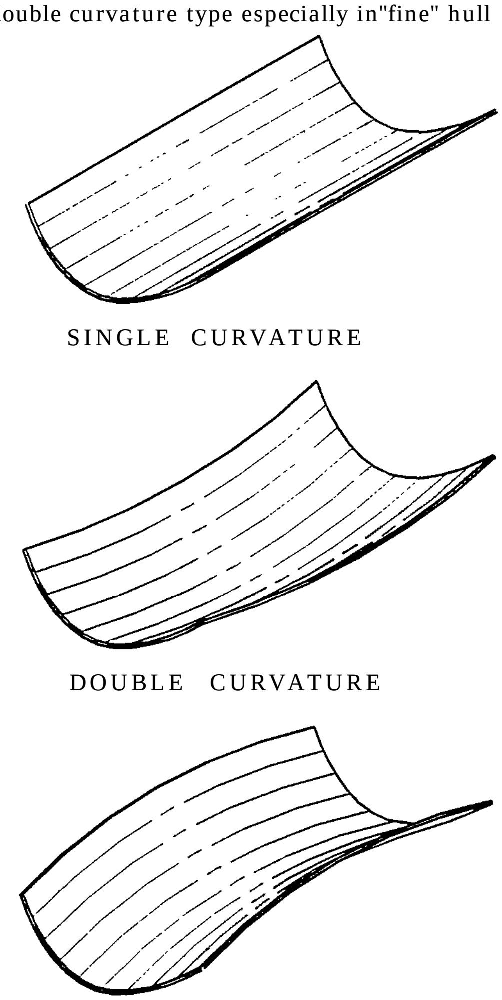
SINGLE CURVATURE is deviation in only one direction.

DOUBLE CURVATURE is deviation in two directions approximately normal to each other.

REVERSE DOUBLE CURVATURE occurs when curvature in the two directions is in opposite directions.

STOCK is excess material added to tie developed flat plate shape. It is usually a fixed allowance such as one inch offset from the developed shape of the seam(s) and butt(s).

Figure 1 gives examples of plates with the above types of curvature. Shell plates in the parallel mid body at the bilge would be single curvature plates. Most other curved shell plates would be double curvature. Shell plates at the stem and stem can be reverse double curvature type especially in"fine" hull forms.



SINGLE CURVATURE

DOUBLE CURVATURE

REVERSE DOUBLE CURVATURE

Figure 1 Curvature Definitions

Modular construction divides a ship's hull into structural blocks. Figure 2 shows the aft portion of the block definition drawing for a typical single screw ship. Figure 3 shows the block above the propeller aperture upside down as it would probably be built. It contains shell plates with significant reverse double curvature as shown. It also shows the four erection seams, two transverse erection butts and the transom erection butt. The upper seams and the transom butt are in the same plane, a water line. The block contains a total of 15 shell plates.

U.S. Shipbuilding Situation

Most shipbuilders in the U.S. are not satisfied with the current shell development situation. They want to be able to cut shell plates neat, That is, without excess material to be "cut in" during fitting the plates on the assembly plattens or structural blocks on the building berth. They view their inability to do this as a limitation of current computer aided lofting systems shell development technology.

While a large number of a ship's shell plates will be flat in the "flat of side" and "flat of bottom,"and developable at the bilge radius in way of the parallel body, there are still many that have complex curvature. It should be obvious to most people involved in the design of ships that normal ship hull shapes do not have developable dates in the area of curved plates.

The following information, for a typical high speed container ship, gives an appreciation of the problem. It had 35,000 lofted parts. Forty-five percent, or about 16,000, are N/C cut parts. The number of shell plates on such a ship was about 800. The shipyard did not their CAL shell development program for about 80 shell plates located in the bow and stem. They used their experience to locate, strake and size these plates and manually develop them. Of these 80, half required forming over a built up "form, set or bed." This same shipyard reported particular problems with shell plates that contained both flat and compound curvature, such as plates crossing the flat of bottom or side tangency lines.

Table I contains similar data for a tanker taken from the Avondale/IHI Shipbuilding Technology Transfer data (2). From this it can be seen that only a small percentage (15. 1%) could be formed by just rolling. The majority of the plates required rolling and then tier forming by line heating. This is probably due to the decision not to use packed rolls for plates with back set, but rather to simply roll them first and use line heating to obtain longitudinal curvature. It should also be noted that a smaller number of actual plates were curved, 296 versus 800. This is because the first vessel had more shape throughout its length or less parallel body than the second ship.

Accuracy control has contributed to the better fit up of internal structure in subassemblies and structural blocks. However, because of the uniqueness of individual curved shell plates, the forming techniques and shape control used, it is difficult to apply the accuracy control process to shell plates. One possible application used by a Japanese shipbuilder for additional marking on shell plates is shown in Figure 4 (3). This method consists of providing a contiuous marking inside the seams and butts at a constant distance for every shell plate. After a shell plate is joined to another, and after the internal structure is completely welded to the shell plates, measurements can be taken from one line to its adjacent plate line, and the distance recorded. This would be applied to all the usual accuracy control analysis tools, and the results used to control the shell shaping/fitting process and to show when improvements were necessary. It would also provide the necessary raw data from which to develop weld shrinkage data.

1. Amount of curved shell plates (one ship)

Aft Construction Part	35 Plates*
Engine Room Part	84 Plates
Cargo Hold Part	112 Plates
Fwd. Construction Part	67 Plates*
TOTAL	298 Plates

NOTE * ESTIMATED FROM DRAWINGS

2. Classification of curved plates bending works

Bending Process	Plate Quantity	Percentage
a) No roll	26	8.7
b) Roller (or press) only	45	15.1
c) Roller and Line Heating	196	65.8
d) Line Heating Only	20	6.7
e) Roller and Forming jig	11	3.7
TOTAL	298	100.0

Rolls=b +c+ e=45 + 196+ 11 =252 plates/1 ship

Line Heating = c + d = 196+20=216 plates/1 ship

TABLE I - CURVED SHELL PLATES ON TANKER

Shipbuilders report that they have problems with individual shell plates fitting pin jigs or egg-crated support structure. Some report that the plate shape is acceptable but that the plate marking is out of alignment with internal structure. This has led them not to mark such plates by N/C, but using the IHI "Key Line" method to lay out the marking after the plates are formed, set on jigs and joined together. The IHI Key Line method was described in detail in the Avondale/IHl Technology Transfer reports (2). Some

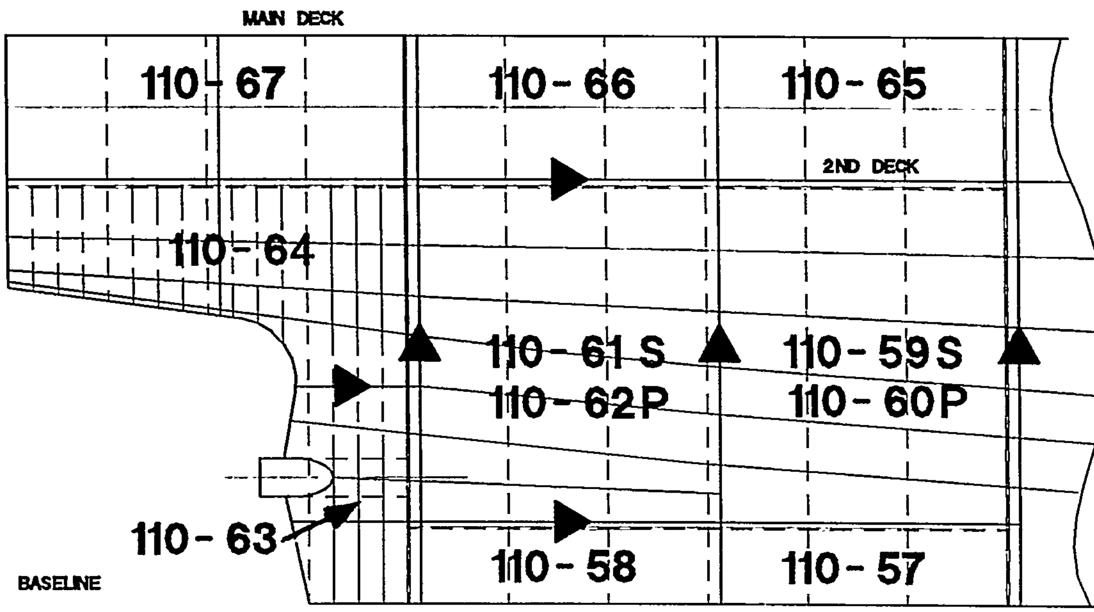


Figure 2 Block Definition Drawing

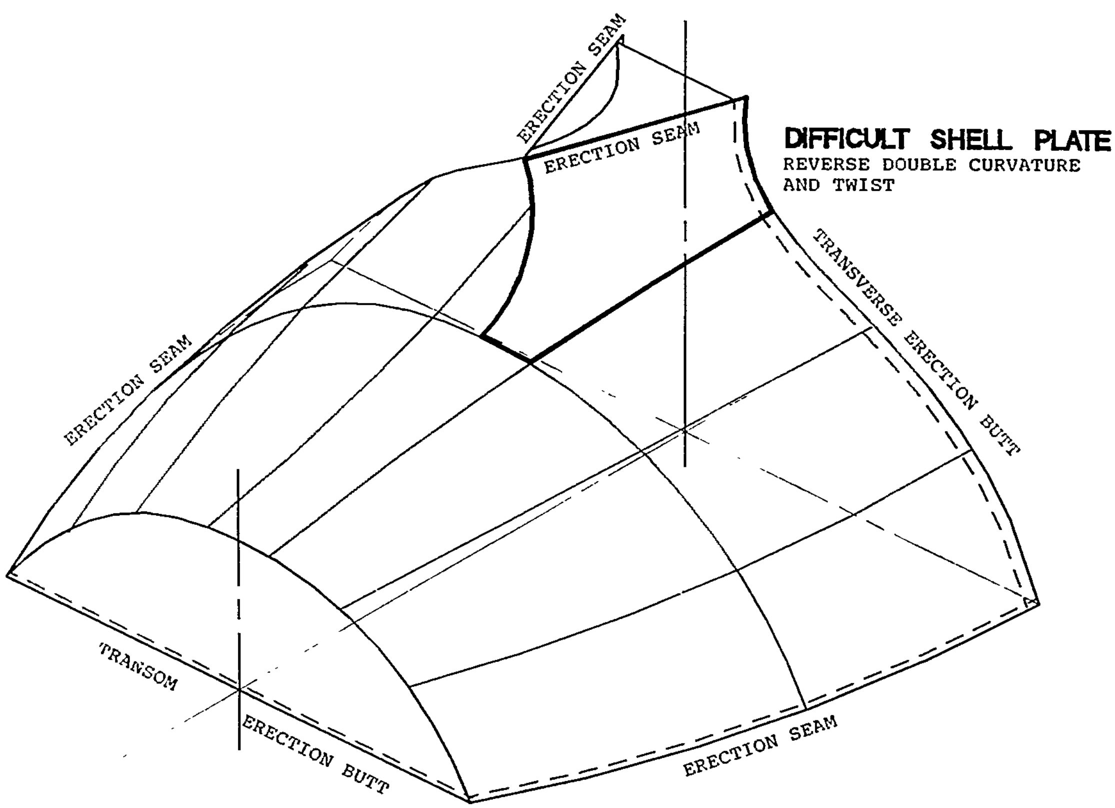


Figure 3 Isometric View of Block 110-64

shipyards use the Key Line method to - the N/C marking after the plates have been joined to form a panel.

Other shipbuilders have problems with the "squareness" of structural block shell plates. They report corners that are up to 3 inches out of true location on a typical block with curved shell plate.

Some shipbuilders report that a major cause of these problems is inadequate definition of the ship's lines, especially in areas of extreme compound curvature. This suggests that better definition through closer spacing of control lines (frames, waterlines and buttocks) is necessary, and better checking for fairness in these regions, and should be a normal part of the process of lines fairing. It is too late to discover bumps, hollows or knuckles in the hull surface during shell plate development. Because of this underdefined lines problem some shipbuilders use Ml scale mock ups to ensure smooth surfaces. Typical areas where this is done are:

- Segmented or "orange peel" plates such as spherical bulbous bow plates, and
- Plates with extreme twist.

The inability to consistently process shell plate with acceptable accuracy forces shipbuilders to "play it safe" and we "stock" on at least one butt and one seam-for the shell on each curved structural block. Then they must cut the stock material off, either as the blocks are aligned, or before erection, through the use of one of the current accurate measurement and alignment methods. Either method requires considerable skill and significant effort (man hours) and time (longer build duration) to accomplish the fit up, removal of the stock and preparing the edge for welding.

Problematic areas of a ship's hull, as identified by shipbuilders, are

- Clipper bows - soft nose stem,
- Cruiser sterns,
- Single screw apertures - stem frames,
- Forebody and aft body shoulders,
- Blocks in the fore and aft bodies with vertical butts and horizontal seams,
- Bulbous bows,
- Sonar domes, and
- Heavy flare in "fine" hulls

Some shipbuilders/designers avoid some of these problems by utilizing large castings, especially for stems and stem frames.

Computer Aided Lofting Developers' Experience

AU the participating CAL developers are aware of shell plate problems, but they do not see them as a limitation of the methods they use. They all point out that shell development of double curvature shell plates is an approximation. There is no exact "unwrapped" flat shape for such curved plates. However, they believe that the approximation gives developed flat shapes for plates that are well within current shipbuilding tolerances. A number of CAL developers stress that all shell plate development requires system-skilled and lofting-experienced users with knowledge of their shipyard's forming and fabrication capabilities and limitations.

Albacore Research recognizes that some extreme double curvature shell plates cannot be adequately expanded into a flat shape. They decide which plates cannot be developed by reviewing the fore and aft deflection of the transverse mesh lines, as shown in the shell expansion view produced by their system (Figure 5). The areas on the hull that cannot be developed show as clear areas, without the mesh.

BMT also recognize that specific areas of certain ship hulls require special attention from experienced Ioftsmen. These loftsmen should not only be experienced in the application of the CAL system but also with their shipyard's shell forming constraints. The BMT system also has an application wherein the direction and magnitude of the curvature are displayed by tufts of principal curvature for the hull surface patches.

Cali points out that "development of a compound curved surface into a flat pattern is a mathematical impossibility." Based on this, the problems are essentially lack of agreement on how much of an approximation is acceptable and lack of allowance by the shipbuilders to account for the inexactness of the approximation for specific shell plates. The accuracy of the approximation is significantly influenced by the selection of the seams and butts. The effect of straking to suit modular construction can create problems by twisting the shell plates. These problems are addressed by considering the correct "priorities" in defining the shell seams and butts. These priorities in correct order should be:

- Hull Form Complexity,
- Straking - Selection of butts at curvature inflexion points,
  Selection of block seams to suit hull shape, and
- Material Utilization.

Coastdesign addresses problems of using small craft developable surfaces when the designer's lines must be maintained. They point out that only the deck edge and the chines should be defined, since the fkame sections will be derived from the developable surfaces in the AutoPlex system. Also, the AutoPlex system

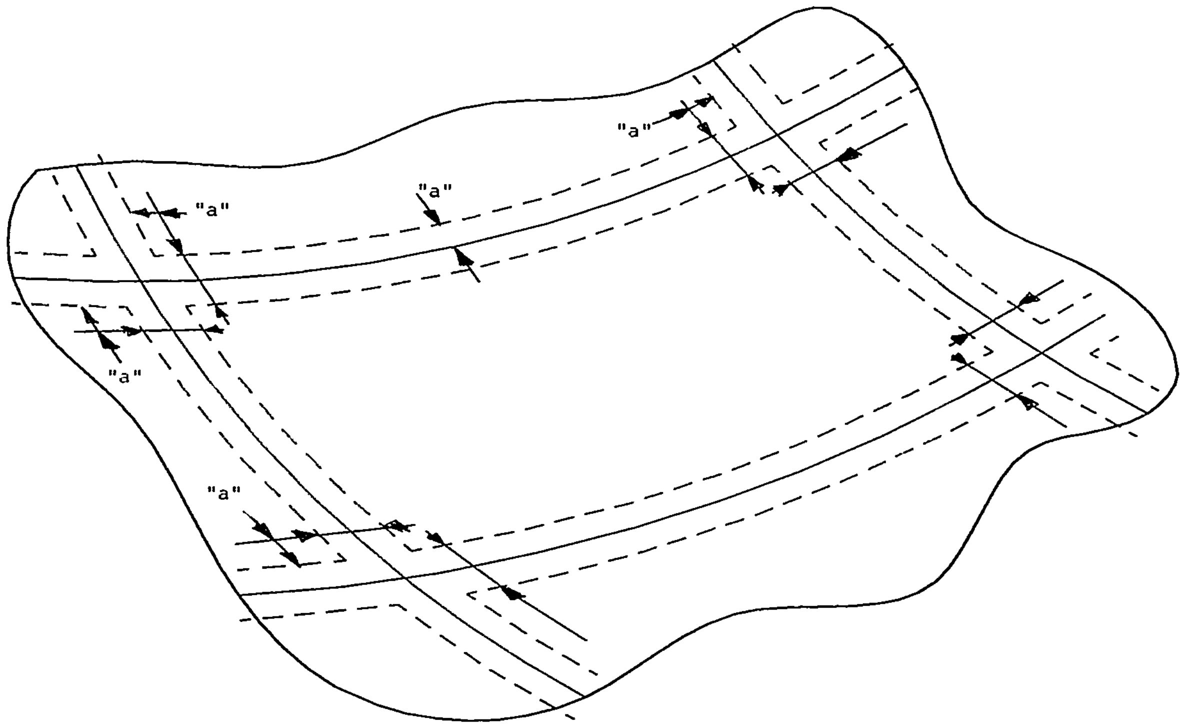


Figure 4 Use of Standard Plate Marking for Accuracy Control

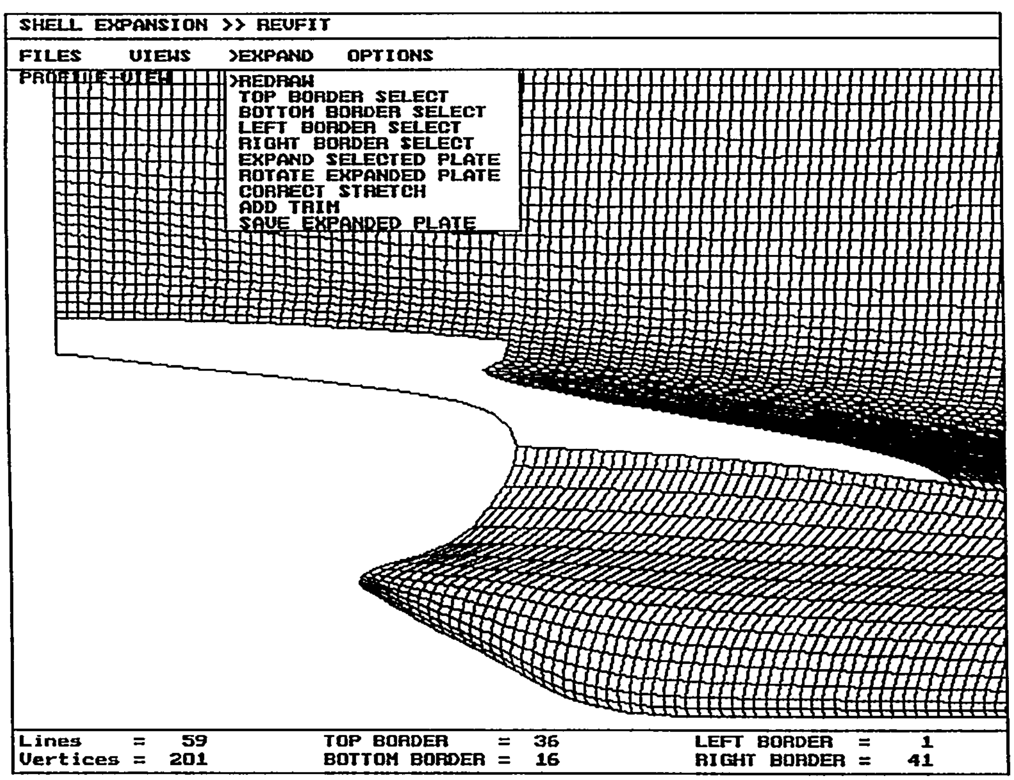


Figure 5 Stern of Vessel with Extreme Fore & Aft Deflections in Transverse Lines

ignores plating thickness. This presents no problem when plating thickness is small. When using thick shell plates, it is possible to overcome this problem in AutoPlex by contracting or expanding the hull lines to account for the plating thickness. Forming of compound curvature plates is basically accomplished by applying strain to the flat plate to deform it into the designed shape. Theoretically, the development of such a plate could be made exact by using a finite element method. However, there is no practical method of applying the strain to the plate exactly as required. Also the resulting deformation would increase and decrease the plate thickness as the plate material was stretched or compressed. Strain maps are produced by the system as the shell development uses a finite element approach. They can be used in the forming process by showing where most of the strain and thus the application of the deforming force should be applied.

Kockums Computer System report that most known shell plate problems can be resolved by correctly orientating individual plates to the expansion curves by using smaller plates where curvature is large. The AUTOKON system's interactive capability makes it relatively easy to try different approaches for the development of difficult shell plates such as smaller plates, transverse expansion curves as an alternative to longitudinal expansion curves, and closer spacing of the expansion curves.

Senermar points out that one of the main problems with shell plate development and forming is the verification of the plate shaping. Of interest is their use of a longitudinal template with transverse roll sets as a means for better control. Senermar also compensates for weld shrinkage, and their system can take care of it in two ways. First,they compensate for weld shrinkage in both the transverse and longitudinal directions by either the same or different shrinkage factors, as selected by the user, and all coordinates of the developed shell plate are automatically adjusted. Second, instead of shrinkage factors, a constant allowance can be added to any of the plate edges.

Foreign Shiubuilfing Situation

Although four foreign shipbuilders were invited to participate in this study, they all declined. As an alternative, papers presented by foreign shipbuilders on the subject were reviewed to obtain some idea of their views (4, 5 & 6). From this review, and personal discussions between them and the author, it can be stated that they do not see the shell development problem as much of a problem as some of the U.S. shipyards see it.

Their message is that successful shell plate forming and erection is as much or more dependent on the material handling and forming equipment, and the skills and training of the forming and erection workers, as it is on the computer aided lofting method accuracy.

Aircraft Industrv Plate DeveIopment Problems

The aircraft industry has some problems that are similar to shipbuilding and others that are unique. As already reported, early aircraft lofting used shipbuilding lofting techniques and loftsmen. Most existing aircraft manufacturers now have their own computer aided lofting system which have been designed to handle their unique needs.

The simple shaped plates in the fuselage, wings and tail present no problems. It is the leading edges of the wings and tail, forward and aft ends of the fuselage and engine nacelle leading edge that require special treatment.. The problems are dealt with by using one of the following approaches:

. Sheet stretching or hammer forming over dies,
. Sheet shot peening, or
. Composite molds.

Where plate development is performed it is done by multiple triangulation and stock is provided for fit up.

DESCRIPTION OF CAL SHELL PLATE DEVELOPMENT METHODS

The six participating CAL developers can be grouped into two PC based and four main frame based systems. However, all the main frame based systems are currently offering stand alone and networked work station versions of their systems.

All systems except Senermar's FORAN use triangulation of many small panels formed by four 3-D space points to obtain the flat developed shape of the plate. However, each uses a slightly different application. Senermar uses a unique approach of building up the Surface definition for each plate from a number of analytical mathematical surfaces, and then developing each one of the set of surfaces and nesting them together to obtain the flat developed shape of the plate. The SPADES system starts its development at one end of the plate, whereas all the others start in the middle.

All systems except ShipCAM3 and AutoPlex/AutoPlate automatically take care of plate thickness and its location relative to the molded line.

All programs provide an N/C code output and a hard copy sketch of the developed plate and its marking. However, ShipCAM3 requires the use of an independent CAD system to accomplish this. They all provide manufacturing aid information. ShipCAM3, AutoSHIP and AUTOKON all offer different versions of plate strain information which can be used by the plate developer to help decide if developed plate is acceptable, and by the forming operator to show where the deforming force should be applied and to what extent.

Table II presents a summary of the participating CAL developers shell development systems.

A detailed description of the shell plate development methods used by the participating CAL developers will be included in the published study report.

CAL SHELL PLATE DEVELOPMENT LIMITATIONS

All of the participating CAL developers were requested to report limitations of their shell development system. They were asked to report on shell plate limitations such as:

- . Maximum or minimum length,
- . Maximum or minimum width,
- . Plate thickness,
- . Maximum backset,
- . Minimum curvature in any direction,
- . Limit of twist,
- . Ratio of backset to length,
- . Ratio of curvature to width, and
- . Ratio of minimum curvature to plate thickness.

As it turned out the items suggested in the above list were not limitations for most of the CAL systems.

While Albacore's system has only been in use for a few years, they have not yet encountered any limitations. However, their system does not currently automatically adjust for plate thickness.

BMT also has no real system limitations. Actual shipyard installation capabilities are dictated by the available material size and handling/processing capabilities of the shipyards rather than their system. Based on this experience BMT suggests the following "practical limitations":

Maximum length20m	(66 feet)	
Maximum width 5m	(16 feet)	
Maximum back set	4cm	(1.5 inches) for rolled plates

BMT also points out that special treatment must be given to soft nose stem and transom plates due to their basic shell development approach rather than degree of "difficulty" of the plate shape.

Coastdesign advises that the AutoPlex system is only intended for developable surfaces, and thus cannot handle reverse double curvature plates such as a flared bow even in a hard chine hull form. Their system also requires that chines must be plate boundaries. The AutoPlate system is unable to give a rolling line because of the development approach and it cannot develop a plate with more than 4 sides. Also, it cannot automatically add stock and plate thickness is not taken into account.

The AUTOKON system limitations are only in the area of number of expansion curves and the number of subdivisions for each expansion curve. However, these are well beyond the needs of any shell plate.

FORAN ha two limitations. The first is for spherical surfaces of small radius, which can, however, be handled by dividing the plate into two smaller plates. The second concerns the angle between the transverse tangents at the upper and lower seams. If this is greater than 90 degrees the plate must be divided into two plates by adding a seam. It is possible to join the two developed parts of the plate by nesting, and avoid cutting the added seam.

Table III presents a summary of the limitations of the participating CAL developers shell development systems as reported by them.

SELECTION OF FIVE TEST CASES

General

Five potentially difficult shell plates were selected for actual development by the participating CAL developers. Rather than generating five new hypothetical plates, these were selected from samples offered by the participating CAL developers. There was no intent to evaluate any of the development results. The resulting data is simply presented for review and use by interested readers.

Description of Rewired Test Cases

The participating CAL developers' reports confirmed the early definition of 'difficult' shell plate regions on a ship's hull. The five test case shell plates are,.

Case 1 (Figure 6) is a plate in the region where the normal hull shape in the bow transitions into the top of a bulbous bow. It involves reverse double curvature and twist.

COMPANY'S NAME	ALBACORE RESEARCH	BMT ICoNS LIMITED	CALI & ASSOCIATES, INC.
SYSTEM'S NAME	ShipCAM3	BRITSHIPS	SPADES
AVAILABLE SINCE	1990	1966	1973
USER INTERFACE	INTERACTIVE GRAPHICS	INTERACTIVE GRAPHICS	INTERACTIVE GRAPHICS
HARDWARE REQUIREMENTS	PC	MAINFRAME, WORK STATION AND PC	MAINFRAME ANDWORK STATION
DATA INPUT	FROM OFFSETS VIA SYSTEM FAIRING PROGRAM. ALSO FROM OTHER SHIP CAD SYSTEMS.	FROM SYSTEM FAIRING AND HULL SURFACE DEFINITION PROGRAM.	FROM SYSTEM FAIRING PROGRAM
SURFACE MODELLING	MESH USING 4TH ORDER B-SPLINES GENERATES 3D VERTICES ON SURFACE. VERTICES JOINED BY STRAIGHT LINES.	SURFACE DEFINED BY BI-CUBIC B-SPLINE PATCHES. TYPICALLY 50 PATCHES FOR ONE SIDE OF A SHIP'S HULL. A NET OF SURFACE 3D POINTS FOR ALL DEFINED SURFACE CURVES IS USED FOR THE SHELL PLATE DEVELOPMENT. NET POINTS ARE JOINED BY SPLINES.	GRID OF 2-D CURVES (TRANSVERSE AND ARBITARY LONGITUDINAL) PLUS 3-D BOUNDARY CONDITION CURVES
SHELL DEVELOPMENT APPROACH	COSINE LAW SINGLE TRIANGULATION OF STRAIGHT LINES BETWEEN VERTICES. STARTS IN MIDDLE OF PLATE AND DEVELOPS MESH COLUMN (TOWARD SEAMS),THEN SUCCESSIVE MESH COLUMNS TOWARDS BOTH BUTTS. MAINTAINS GIRTH LENGTHS OF MESH CONSTANT AND TAKES ACCOUNT OF ALL DEVELOPMENT DEFORMATION IN LONGITUDINAL DIRECTION.	SINGLE TRIANGULATION FOR EACH SET OF FOUR NET POINTS. STARTS IN THE MIDDLE OF THE PLATE, DEVELOPS TOWARDS THE SEAMS AND THEN ALONG A CENTRAL BAND TOWARD BOTH BUTTS. REMAINING FOUR PORTIONS OF PLATE ARE DEVELOPED IN A WAY THAT TENDS TO MAINTAIN THE OVERALL SEAM AND BUTT LENGTHS TO PRESERVE MATING WITH ADJACENT PLATES	USES BOTH GIRTH LENGTH FOR SIMPLE PLATES AND SINGLE TRIANGULATION FOR COMPOUND CURVATURE PLATES. WORKS FROM PLATE END CLOSEST TO AMIDSHIPS. a GRID OF UP TO 9 BY 50 POINTS IS USED FOR COMPUTING SURFACE DISTANCES BETWEEN POINTS. THE COMPUTED DISTANCES ARE THE USED TO TRIANGULATE THE POINTS INTO THE EXPANDED PLANE. TRIANGULATED POINTS ARE EVENTUALLY CURVE FITTED TO CREATE THE FINAL OUTPUT OF THE PLATE OUTLINE AND ALL INTERNAL LAYOUT.
PLATE MARKING	ONLY MARKS WATERLINES, FRAMES AND BUTTOCKS ON PLATE	ANY DEFINED CURVE/LINE ON SURFACE. ROLL LINE AND SIGHT LINE (OPTIONAL)	ANY DEFINED CURVE/LINE ON SURFACE AND ROLL LINE
UNIQUE ATTRIBUTES	STRAIN MAP. LONGITUDINAL DEFORMATION TABLE.	ABILITY TO ASSESS FAIRNESS OF SURFACE CURVES AND LOCAL SURFACE CURVATURE. PLATE CAN HAVE UP TO 8 SIDES TRIANGULATION ASPECT RATIO VARIATION WARNING. PROVISION OF CHECKING DIMENSIONS. ABILITY TO HANDLE ZERO GIRTH BUTTS. CAN HANDLE 8 SIDED PLATES. INPUT AND OUTPUT UNITS CAN BE DIFFERENT. CAN ADJUST FOR WELD SHRINKAGE	USE OF OPTIONAL REVERSE END DEVELOPMENT AS A CHECK ON NORMAL DEVELOPMENT. EXTENT OF DIFFERENCE CAN BE USED TO DECIDE NEED FOR STOCK. USES OPPOSITE DIAGONAL AS A CHECK ON GRID DISTORTION.

TABLE II - PARTICIPATING CAL DEVELOPER SYSTEM DESCRIPTION SUMMARY

COMPANY'S NAME	COASTDESIGN, INC.	KOCKUMS COMPUTER SYS. AB	SENERMAR
SYSTEM'S NAME	AutoSHIP	AUTOKON	FORAN
AVAILABLE SINCE	1972	1968	1972
USER INTERFACE	INTERACTIVE GRAPHICS	INTERACTIVE GRAPHICS	INTERACTIVE GRAPHICS
HARDWARE REQUIREMENTS	PC	MAINFRAME WORK STATION	MAINFRAME WORK STATION
DATA INPUT	FROM HULL DESIGN AND FAIRING SYSTEM PROGRAM	FROM SYSTEM DESIGN AND FAIRING PROGRAM	FROM SYSTEM DESIGN AND FAIRING PROGRAM
SURFACE MODELLING	USES 1ST, 2ND AND 3RD ORDER B-SPLINES IN TRANSVERSE DIRECTION AND CUBIC POLYNOMIAL SPLINES IN LONGITUDINAL DIRECTION.	3D MODEL OF SHIP'S HULL CONSISTING OF SCULPTURED AND PLANAR SURFACES. SCULPTURED SURFACE STORED AS MESH OF LINES	3D MODEL OF SHIP HULL CONSISTING OF PARAMETRIC SURFACES
SHELL DEVELOPMENT APPROACH	AUTOPLEX DEVELOPABLE SURFACE PROGRAM DETERMINES RULE LINES BETWEEN LONGITUDINAL KNUCKLE CURVES. AUTOPLATE FOR COMPOUND CURVATURE PLATES USES A PATENTED FINITE ELEMENT METHOD TO EXPAND SURFACE PATCHES WHICH ARE REPRESENTED BY 3D POINTS OR NODES. THE GEODESIC CURVE LENGTH (GEODESIC CURVE IN 3D IS STRAIGHT LINE IN 2D) BETWEEN NODES AND USES IT IN A SILIMAR WAY TO SINGLE TRIANGULATION.	USES GRID OF EXPANSION CURVES AND CROSSING CURVES. EXPANSION CURVES ARE SEGMENTED INTO 4 TO 20 PARTS GIVING 5 TO 21 3D POINTS ON EACH EXPANSION CURVE. PATCH OF PLATE BETWEEN EACH EXPANSION CURVE AND EACH CROSSING CURVE IS DEVELOPED BY TRIANGULATION USING TRUE GIRTH LENGTH ON THE EXPANSION CURVES AND CIRCULAR INTERPOLATION BETWEEN OTHER CURVES. OBTAINS 2D POINTS FOR DEVELOPED PLATE VIA COON'S PATCHES FOR 3D GRID	TRANSFERS HULL SURFACE FOR EACH PLATE INTO SETS OF DEVELOPABLE SURFACES (CYLINDERS AND CONES). USES NET OF 65 POINTS DETERMINED BY INTERSECTION OF 13 TRANSVERSE CURVES AND 5 LONGITUDINAL CURVES. FIRST CHECKS FOR CYLINDRICAL FIT OF SURFACE. IF NOT ACCEPTABLE FITS TWO CONIC SURFACES WITH COMMON GENERATRIX. CHECKS MEAN SQUARE ERROR AND DEVIATION BETWEEN REAL AND ADJUSTED SURFACES. MAY SELECT MORE THAN TWO CONIC SURFACES IF VALUE OF GAUSSIAN CURVATURE IS GREATER THAN A PREDETERMINED VALUE. THIS ALL OCCURS AUTOMATICALLY BASED ON MANY YEARS OF EXPERIENCE WITH THE SYSTEM.
PLATE MARKING		ANY DEFINED CURVE/LINE ON SURFACE AND ROLL LINE	ANY DEFINED CURVE/LINE ON SURFACE AND ROLL LINE
UNIQUE ATTRIBUTES	STRAIN MAP	USER OPTION TO SELECT DIRECTION AND NUMBER OF EXPANSION CURVES. CAN HANDLE PLATES CROSSING CENTER LINE. CAN HANDLE UP TO 99 SIDED PLATES. CAN ADJUST FOR WELD SHRINKAGE. CALCULATES STRETCH AND COMPRESSION IN FORMED PLATE.	CAN HANDLE BUTTS THAT ARE NOT PARALLEL TO FRAME LINES. CAN ADJUST FOR WELD SHRINKAGE.AUTOMATICALLY REORIENTS PLATES IN WAY OF FLAT OF SIDE AND BOTTOM TANGENCY LINES TO AVOID HIGHVALUES OF DERIVATIVES OF 3D POINT CONVERSION TO 2D POINTS.PRODUCTION AIDS SUCH AS FLAG TO SHOW IF PLATE CAN BE CUT WITH PARALLEL TORCHES. CHECKING DIMENSIONS AUTOMATICALLY GIVEN TO IMPROVE PLATE USAGE DURING INTERACTIVE PROCESS.

TABLE II (CONTINUED)

COMPANY'S NAME	ALBACORE RESEARCH	BMT ICONS LIMITED	CALI & ASSOCIATES, INC.	COASTDESIGN, INC.	KOCKUMS COMPUTER SYS. AD	SENERMAR
SYSTEM'S NAME	shipCAM3	BRITSHIPS	SPADES	AutoSHIP	AUTOKON	FORAN
SYSTEM LIMITATIONS						
MAXIMUM LENGTH		TYPICALLY (20M)66FT			(33M)1OOFEET	
MINIMUM LENGTH		TYPICALLY (1 M)3FT				
MAXIMUM WIDTH		TYPICALLY (3 M)16FT			(33M)IOOFEET	
MINIMUM WIDTH		TYPICALLY (1 M)3FT				
MAXIMUM BACKSET		(4CM)L5 INCHES				
OTHER	PLATE BOUNDARIES MUST BE EITHER MESH LINES OR PARALLEL TO 3 PRINCIPAL PLANES DOES NOT HANDLE PLATE THICKNESS AUTOMATICALLY CAN ONLY MARK WATERLINES, FRAMES AND BUTTOCKS. DECKS WITH CAMBER/SHEER AND LONGITUDINALS CANNOT BE MARKED NO ROLL LINE, ROLL SETS OR PIN JIG CAPABILITY MUST BE TRANSFERED TO A CAD SYSTEM FOR DETAILING ONLY ADDS STOCK TO BUTTS. NO CAPABILITY TO ADD STOCK TO SEAMS	SYSTEM USUALLY BASED ON A FRAMES DEFINITION (BUTTOCK VIEW) OF SHELL PLATE. HOWEVER PLATES CAN OPTIONALLY BE DEFINED ON WATERLINES TO HANDLE SOFT NOSE STEM PLATES. TRANSOM PLATES REQUIRE INTER-MEDIATE MANIPULATION	MAXIMUM OF 8 SEGMENTS PER TRANSVERSE CURVE SHELL PLATES LIMITED TO TWO SEAMS AND TWO BUTTS. PLATES WITH MORE BOUNDARIES OR WITH BUTTS THAT ARE NOT PARALLEL TO FRAMES MUST BE DEVELOPED IN PART GENERATION PROGRAM	DOES NOT HANDLE PLATE THICKNESS AUTOMATICALLY DOES NOT ADD STOCK DOES NOT HANDLE PLATES WITH MORE THAN FOUR BOUNDARIES MUST BE TRANSFERED TO CAD SYSTEM FOR DETAILING NO ROLL LINE, ROLL SETS OR PIN JIG CAPABILITY	MAXIMUM NUMBER OF EXPANSION CURVES IS 100 MINIMUM OF 4 AND MAXIMUM OF 20 SEGMENTS PER EXPANSION CURVE	SMALL IUUXUS SPHERICAL SURFAC MUST BE DIVIDED SMALL PLATES EXTREME TRANSVERSAL CURVATURE SUCH THAT ANGLE BETW TRANSVERSE TANGENTS AT UPP AND LOWER SEAMS LESS THAN 90 DEGI MUST BE SPLIT INT TWO PLATES BY ADDING A SEAM PR4CTICAL LIMITATIONS OF SHIPYARD TOOLS A DEFINED IN STAND PRODUCTION METHODS. WARNING MESSAG CAN BE PROVIDED.

TABLE III - LIMITATIONS OF PARTICIPATING CAL DEVELOPERS SHELL DEVELOPMENT SYSTEM SUMMARY

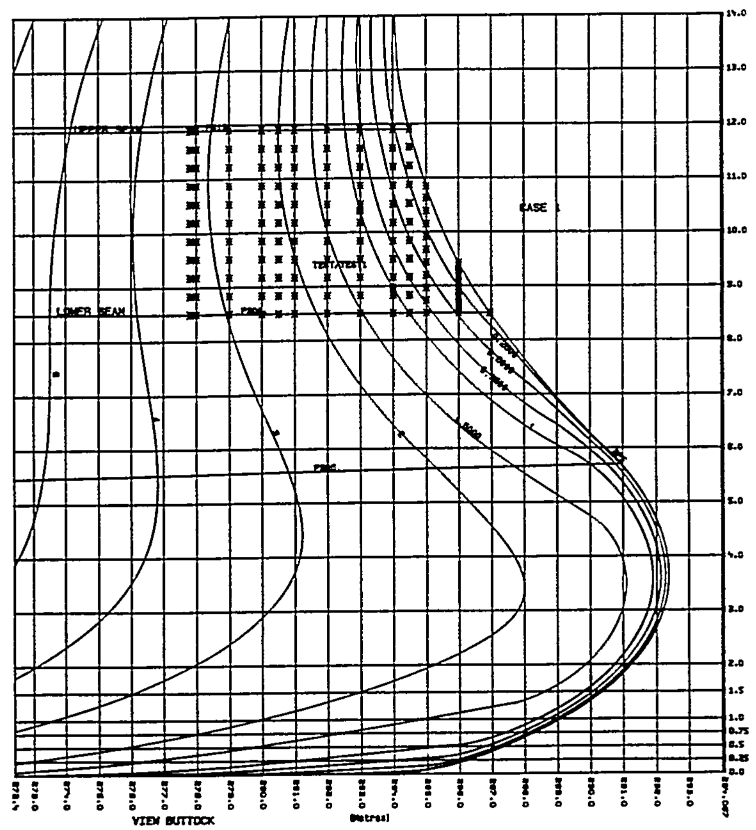


Figure 6 Case 1 - Plate above a Bulbous Bow

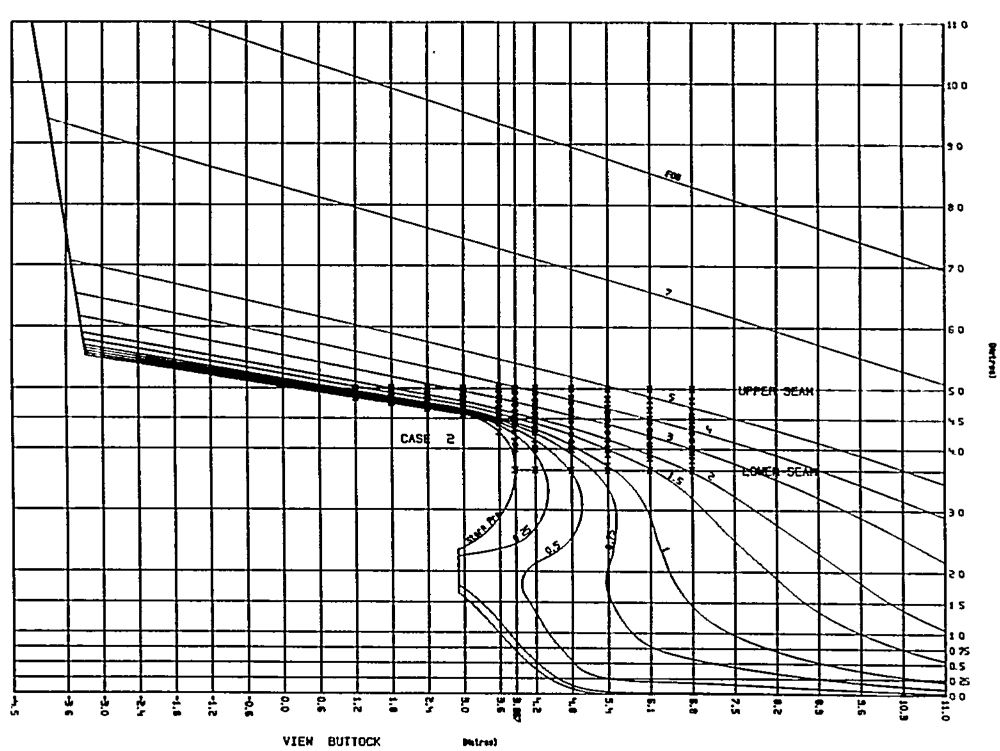


Figure 7 Case 2 - Plate in way of Stern Aperture

Case 2 (Figure 7) is a plate in way of the top of a single screw aperture. It involves more than 4 sides, both reverse and regular double curvature and twist.

Case 3 (Figure 8) is a plate in way of the hull shoulder close to the flat of bottom tangency curve. It only involves double curvature.

Case 4 (Figure 8) is a plate where the upper seam is the erection seam and is in the horizontal plane to suit block construction. It involves double curvature and twist.

Finally, Case 5 (Figure 9) is a plate which is adjacent to the underhung, faired bulbous bow, sonar dome found on many current warships. It also involves reverse double curvature and twist.

For each of the five test cases, the following data was be provided to and used by each participating CAL developer:

1. OIXsets for sections, waterlines and buttocks in way of each plate.
2. IGES format hi-cubic B-spline surface patches in way of each plate.
3. Definition of seams and marking curves.
4. Body, profile and plan views for each plate labeled for seams, butts and marking curves.

FIVE TEST CASE RESULTS

As the paper deadline neared, only three of the six participating CAL developers had completed the development of the five test cases.

As a quick comparison of the different developments the 1:10 scale plots of the developed plates were examined. For test cases 1, 3 and 4 there were no observable dfferences. Even the roll lines matched. However, for test cases 2 and 5 the difference was noticable, and for test case 5, which is the most complex plate of the five tested, there were considerable differences.. Figure 10 shows the test case 5 developed plate outlines superimposed on each other, and the difference in shape can be easily seen.

As a more precise comparison, the corner coordinates of the developed plates were tabulated and compared. They are shown in Table IV.

The differences are up to 50 millimeters in length and 25 millimeters in Widm for test cases 1, 3 and 4. The significant differences, in shape, for test case 5 described above, can be clearly seen by the significant differences in the comer coordinates. However, it should be mentioned that all three CAL developers recommended that this complex plate should be split into three plates. All six participating CAL developers have been asked to do this, but the redevelopments were not received in time to be included in the paper.

This lack of agreement by the three diferent CAL systems, cleary shows the need for stock (excess material) on such complex shell plates. Also, the amount of stock should be at least 100 millimeters to cuver the greatest differences.

STUDY CONCLUSIONS AND RECOMMENDATIONS

<u>Conclusions</u>

Shell development problems are viewed differently by shipbuilders and CAL developers. As computer aided shell plate development methods have been in use for over 20 years, it would seem reasonable to expect developers and users (shipbuilders) to have worked together on the problems, or at least be in agreement as to what they are.

Foreign shipbuilders do not show the same concerns as some of the U.S. shipbuilders. Their message is that successful shell plate forming and erection is as much or more dependent on the material handling and forming equipment, and the skills and training of the forming and erection workers as it is on the computer aided lofting method accuracy.

While improvements have been made to all of the CAL developers' shell development systems over the years of use, they have been in the user interface and to take advantage of computer improvements. There has been no major new approach that significantly added to the accuracy of the developed plate flat shape.

The CAL systems are not "expert systems" nor do they inco~orate "artificial intelligence." This means that the use of the system and specifically shell development will be highly dependent on the user's skill level as a loftsman as well as experience with the system.

For most of the compound curvature shell plates on a ship's hull, the accuracy of the shell development systems is well within normal shipbuilding tolerances.

The shipbuilders' goal, to cut <u>all</u> shell plates neat probably will not be realized in the foreseeable fhture. This is due to two facts, namely

1. It is mathematically impossible to develop an exact flat pattern for any plate with compound curvature.
2. Shipbuilding plate forming tools and operator skills do not have the required consistent and repeatable accuracy.

The development of the same plate by different CAL systems is surprisingly inconsistent and gets progressively worse as the shell plates become more complex. However, even in this case the consistency

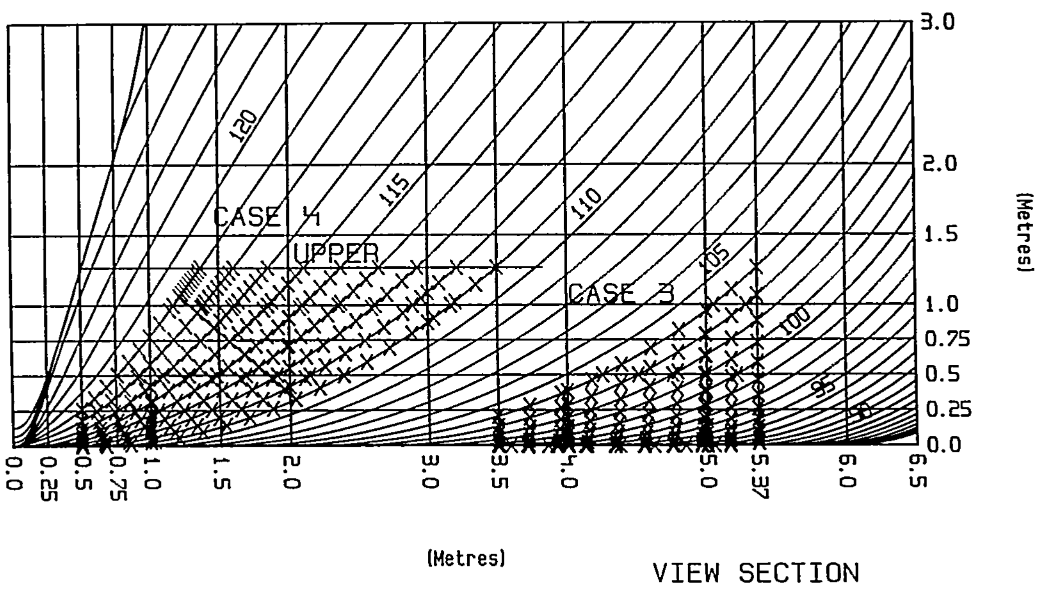


Figure 8 Cases 3 & 4 - Plates in way of Hull Shoulder and Bottom Flat Tangency

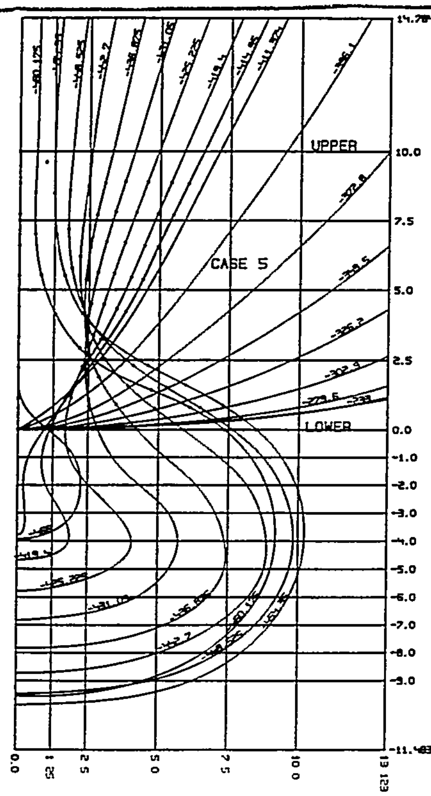


Figure 9 Case 5 - Plate in way of Sonar Dome

	BOTTOM LEFT	TOP LEFT	TOP RIGHT	BTM RIGHT	BTM CENTER
TEST CASE 1					
BMT	0/0	0.027/3.785	5.184/3.506	6.469/0	
FORAN	0/0	0.017/3.405	5.222/3.507	6.469/0	
KCS	0/0	0.007/3.389	5.202/3.587	6.488/0	
TEST CASE 2					
BMT	0/0	0.818/1.019	7.912/0.949	5.753/-2.198	2.159/-2.261
FORAN	0/0	0.797/1.016	7.890/0.946	5.741/-2.195	
KCS	0/0	0.825/1.013	7.532/1.100	5.643/-2.268	2.079/-2.268
TEST CASE 3					
BMT	0/0	0.041/1.874	8.555/2.057	8.408/-0.106	
FORAN	0/0	0.047/1.865	8.587/2.067	8.401/-0.111	
KCS	0/0	0.026/1.871	8.548/2.066	8.408/-0.099	
TEST CASE 4U					
BMT	0/0	-0.090/1.720	5.649/0.253	5.703/0	
FORAN	0/0	-0.085/1.743	5.718/0.245	5.710/0	
KCS	0/0	-0.079/1.741	5.713/0.257	5.693/0	
TEST CASE 4L					
BMT	0/0	0/1.593	5.699/1.091	5.611/0	
FORAN	0/0	0/1.590	5.708/1.072	5.611/0	
KCS	0/0	0/1.592	5.679/1.082	5.609/0	
TEST CASE 5					
BMT	0/0	1.330/2.528	16.470/2.528	16.509/-0.978	
FORAN	0/0	0.035/3.503	15.139/3.503	16.347/0.808	
KCS	0/0	0.567/3.492	14.358/3.488	16.134/1.090	

TABLE IV - COMPARISON OF DEVELOPED PLATE CORNER COORDINATES

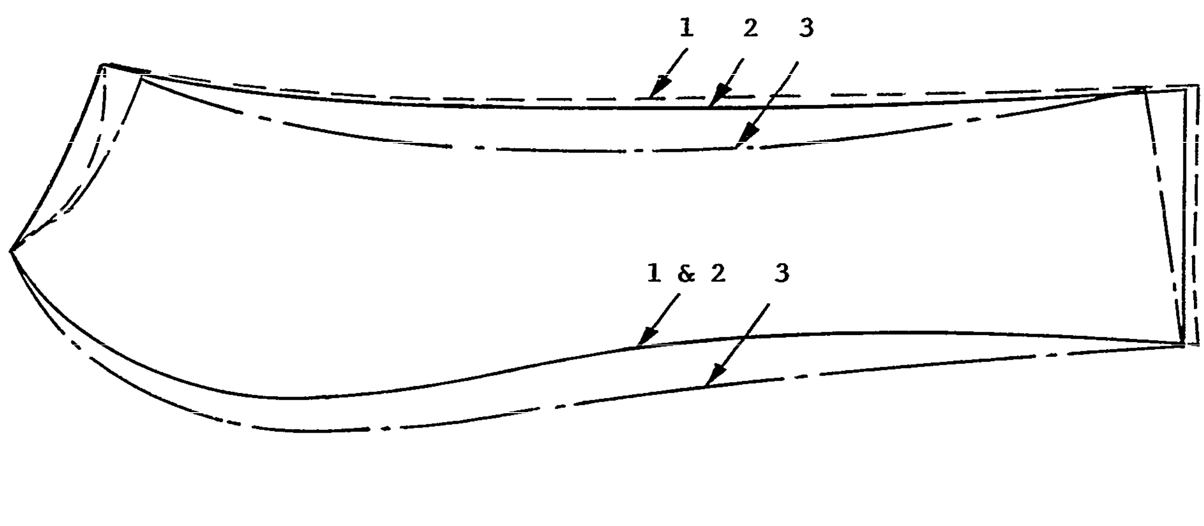


Figure 10 Test Case 5 Developed Plate Outlines

can be improved by dividing the complex shell plate into a number of smaller plates.

Recommendations

It is recommended that:

A study be undertaken of shipbuilding forming methods and the application of accuracy control to improve shell plate forming accuracy and consistency be undertaken.

A study be undertaken to develop ways to use advanced measuring devices, such as laser theodilites, for the checking and control of shaped shell plate forming.

Shipbuilders and CAL developers work together to develop new and improved computer developed data to assist shell plate forming operators to attain better accuracy and consistency.

ACKNOWLEDGEMENTS

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